Does climate adaptation of vulnerable households to extreme events benefit livestock production?

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ABSTRACT

Extreme climate events have become more frequent and severe as a result of climate change. In semi-arid pastoral regions, extreme drought is harmful to livestock production and to vulnerable human communities and livelihoods. In this study, we considered extreme drought in semi-arid regions and investigated climate adaptations taken by the local vulnerable households and their effects on livestock production. We first analyzed the characteristics of spatio-temporal variation of extreme drought in Hulun Buir, Inner Mongolia, China, during 1980–2015 by using the FAO Penman–Monteith model and then applied stochastic frontier analysis to evaluate the technical efficiency of livestock production of 126 pasturing households. We further explored the effects of climate adaptations to extreme drought on the technical efficiency of livestock production. The results showed that the average frequency of extreme drought in Hulun Buir was 4.6 month/year and displayed a decreasing trend varying from southwest to northeast during 1980–2015. Based on the survey data, the average technical efficiency of livestock production of the local households was 0.530 in 2015, which could be greatly improved. The adaptations of the households significantly positively increased the technical efficiency of livestock production. Purchasing more forage and selling more livestock were the two most frequently adopted and effective adaptive measures for the response of vulnerable households in Hulun Buir to extreme drought risks. Further policy options were provided to improve livestock production as well as rangeland protection and restoration for coping with extreme drought in the context of climate change in semi-arid pastoral regions.

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1. Introduction

Climate change is one of the greatest threats to human life in the 21st century. It directly affects the lives of millions of people around the planet, affecting environmental quality and resident property security through changes to weather patterns, sea level rise, and increased frequency of extreme weather (Deng et al., 2013; UN, 2016; Kumar and Kumar, 2016). Global warming brings huge challenges to not only natural ecosystems but also sustainable development (Deng and Bai, 2014; Nigam et al., 2017). Global warming prevents crop growth, promotes drought of cultivated land, and represents a serious threat to food production (Zhan et al., 2013; Zhang et al., 2017; Wang et al., 2017). As for ecosystems, climate change phenomena such as El-Nino, melting snow and decreasing forest cover directly affect biodiversity.

Extreme climate events have become more frequent and severe as a result of climate change. Impacts derived from climate-related extremes, such as wildfires, heat waves, droughts, floods, and cyclones, indicate serious vulnerability of human and earth systems to climate change (IPCC, 2014). The IPCC forth assessment of climate change indicated that it is urgent to adapt to climate change in the next few decades (Solomon et al., 2007). In the context of local climate circumstances and human characteristics, some

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actions have been taken to reduce risks (Wang et al., 2017). Low-income countries and regions have little capacity to deal with rising sea level, disease spread, crop yield reduction, and destruction of infrastructure. Therefore, they will suffer more strongly from the impacts of climate change than wealthy countries and regions. The negative impacts of climate change will affect the livelihoods of vulnerable, resource-poor, marginal, and smallholder populations in different agro-climatic conditions even with best adaptive measures and use of indigenous technical knowledge (Maiti et al., 2014, 2015).

Extreme droughts are harmful to livestock and even to vulnerable human communities and livelihoods. The lack of precipitation leads to grassland degradation and feedstuff reduction, thus affecting livestock production. China has become one of the largest producers of livestock since reform and opening (FAO, 2006). Grasslands in China cover approximately 40% of the total national land (Hu et al., 2016). Plant-based and animal-based protein is projected to increase in China by 25% and 80%, respectively, between 2005 and 2030 (Ma et al., 2013). In response to these demand trends, it is important to adopt adaptation measures to extreme droughts to sustain and increase agricultural production in arid and semi-arid regions. More research and investment are needed to verify the effects of adaptation practices, to increase the affordability of mitigation practices, and to avoid negative impacts on livelihoods, livestock production, and the eco-environment (Herrero et al., 2016). It is necessary to assess adaption measures from multiple objectives and multiple spatio-temporal scales. Scientific estimation and analysis of technical efficiency of livestock production is needed to analyze the impacts of extreme climate events, climate change, and adaptation measures on livestock development.

Empirical studies focus on reviewing climate change adaptation (Descheemaeker et al., 2016) and actual choices of agricultural producers for coping with climate change (Hassan et al., 2008; Deressa et al., 2009; Pan et al., 2016). In recent years, more studies apply economic methods as well as models assessing adaptation measures. Fankhauser (2010) reviewed large amounts of research into adaptation costs, which estimated costs ranging from $25 billion/year to over $100 billion for the next two decades through the method of 'median' climate change. Dittrich et al. (2017) applied a 'robust decision making' method to deal with different degrees of complexity and choices. Weindl et al. (2015) explored whether it is effective to adopt livestock system transitions as an adaptation tactic, based on a comprehensive impact modeling chain. Descheemaeker et al. (2017) assessed adaptation measures for climate change in Africa by developing a dynamic modeling framework that integrates crop, climate, pasture, and livestock models. However, there have been few studies focusing on the evaluation of livestock production based on productive efficiency analysis. Moreover, there is a lack of analysis on the effects of climate change adaptation on the technical efficiency of livestock production, in response to extreme drought. In this context, this paper aimed to describe and evaluate climate change features of extreme drought and adaptation measures to extreme drought by integrating meteorological measurements and econometric methods.

Many scholars have proposed approaches for evaluating the technical efficiency of production. These methods, such as parametric approach of stochastic frontier analysis (SFA) (Aigner et al., 2006) and the non-parametric data envelopment analysis (DEA) approach (Färe et al., 1989), analyze the efficiency of inputs and outputs during production. Use of DEA will lead to some errors in evaluating performance, especially when using macroeconomic data, because it ignores random noise (Lin and Du, 2013). In contrast, production function in SFA includes random errors and an inefficiency term (Bai et al., 2016). Based on the SFA method, Huang et al. (2016) evaluated the efficiency of livestock production on the Qinghai–Tibetan Plateau considering environmental performance indicators. Cabrera et al. (2010) measured production performance and its influencing factors for 273 dairy farms in Wisconsin, USA.

The objective of this study was to investigate climate adaptation by vulnerable households to extreme drought and examine the impact of adaptation on livestock production. In this paper, we first applied the Food and Agriculture Organization of the United Nations (FAO) modified Penman–Monteith model to calculate the frequency of extreme drought and analyzed the characteristics of spatio-temporal variation of extreme drought during 1980–2015 in Hulun Buir, Inner Mongolia, China. Based on the results of the field research, we then calculated the technical efficiency of livestock production of 126 households and further investigated the effects of climate adaptation to extreme drought on the technical efficiency of livestock production by applying the SFA method and the Tobit model.

2. Study area

Located in Northeast China, Hulun Buir Prefecture in Inner Mongolia, (47°05′N–53°20′N, 115°31′E–126°04′E) covers about 253,000 km^2 and is home to 3 million people (i.e., equal to the population of Mongolia). The grassland vegetation is distributed from west to east, spanning three zones: arid grassland, meadow steppe, and forest steppe. The annual accumulated precipitation increases from the west to the east. Annual precipitation was 200–300 mm in summer and 40–80 mm in winter. The annual temperature shows a decrease–increase–decrease trend from the west to the east, ranging from 2.43 °C to 4.85 °C (Fig. 1). Hulun Buir is one of the typical semi-arid regions of China, which is characterized by climatic variability and traditional livelihoods based on natural resources. Extreme weather events seriously constrain livelihoods in these vulnerable eco-regions, especially as climate change accelerates. Mixed pastoral and agro-pastoral communities suffer from extreme drought in this region.

Hulun Buir prairie grassland is one of the main grassland areas in China. The animal husbandry of Hulun Buir is important to the local economic progress and social stability. The area of grassland is about 1 million km^2, accounting for 38.2% of the total area. There were 44,000 laborers working in animal husbandry and fishery industry in 2015, more than 15% of the total population. The livestock number was 8.355 million at the end of 2015, representing an increase of 280% relative to the 2000 level (Fig. 2).

3. Methodology and data

3.1. Methodology

3.1.1. The FAO Penman–Monteith model

The data including daily precipitation, daily average temperature, daily maximum temperature, daily minimum temperature,
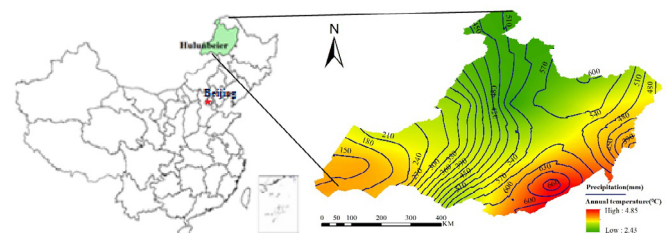

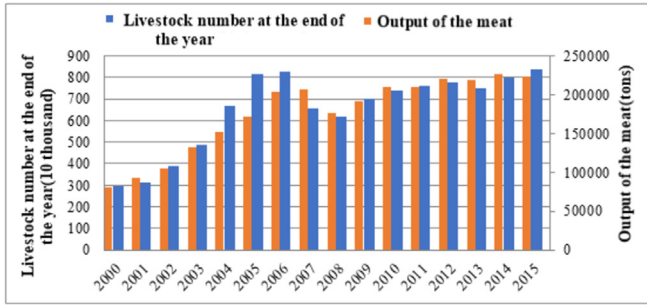**Fig. 1.** Study area and temperature and precipitation in 2015.

Fig. 2. Livestock number and output of meat in 2015 in Hulun Buir.

sunshine hours, daily average relative humidity, and daily average precipitation of 12 meteorological stations in Hulun Buir area from 1980 to 2015 were used to calculate the extreme drought index. Monthly potential evapotranspiration and precipitation data were taken from daily potential evapotranspiration calculated at each meteorological station and monthly surface humidity index was calculated based on these data. The humidity index is a physical quantity that is ideal to characterize wet and dry surface conditions (Hulme et al., 1992; Dikmen and Hansen, 2009). There are many kinds of calculation methods (Yin et al., 2008; Matsui and Osawa, 2015) and the definition of the normalized variable of the humidity index equal to or less than −0.5 is defined as extreme drought (Gavilán and Castillo-Llanque, 2009). In this paper, we chose the FAO Penman−Monteith model, modified from the original Penman−Monteith model by the FAO in 1998, to calculate the frequency of extreme drought. The equation is as follows:

$$K = \frac{R}{ET_0} \tag{1}$$

where K represents the humidity index, R represents precipitation(mm/d), and ET_0 represents potential evapotranspiration (mm/d).

The format to calculate potential evapotranspiration ET_0 was as follows (Allen, 1998):

$$ET_0 = \frac{0.48\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \tag{2}$$

where ET_0 represents potential evapotranspiration (mm/d), R_n represents net radiation (MJ m^{-2} d^{-1}), G represents soil heat flux (MJ m^{-2} d^{-1}), γ represents the dry-wet constant (kP$_a$/°C), Δ represents saturated water pressure curve slope (kP$_a$/°C), U_2 represents the wind speed at 2 m height (m/s), e represents average saturated water pressure (kP$_a$), e_a represents actual water pressure (kP$_a$), and T represents average temperature (°C).

Inverse distance weighted (IDW) interpolation is a universal and simple interpolation method, belonging to accuracy interpolation (Lu and Wong, 2008). It is based on principle of similarity, in which the similarity between two objects increases as the distance between the two objects decreases. In this study, we used ArcGIS 10.2 to calculate the spatial distribution of extreme drought and inclination rate of extreme drought in Hulun Buir, using IDW interpolation (Chen, 2012), and then analyzed the spatial distribution of these results.

3.1.2. Stochastic frontier analysis

This paper aimed to calculate technical efficiency of livestock production. To consider multiple outputs and inputs, we chose the SFA model, which can be applied to analyze multi input and output

problems. Following the practices in most relevant research, we selected the translog production function for use in this paper:

$$\ln Y_i = \beta_1 \ln x_{1i} + \beta_2 \ln x_{2i} + \beta_3 \ln xa_{3i} + \beta_{12} \ln x_{1i} \ln x_{2i}$$
$$+ \beta_{13} \ln x_{1i} \ln x_{3i} + \beta_{23} \ln x_{2i} \ln x_{3i} + \frac{1}{2}\beta_{11}(\ln x_{1i})^2$$
$$+ \frac{1}{2}\beta_{22}(\ln x_{2i})^2 + \frac{1}{2}\beta_{33}(\ln x_{3i})^2 + (v_{it} - u_{it}) \tag{3}$$

where β is the parameter vector to be estimated through observations; $v_{it} \sim N(0, \sigma_v^2)$ was random noise variables that was independent of u_{it}, which is the non-negative random error term, and it complied with truncated normal distribution, $N(u_{it}, \sigma_u^2)$.

Technical efficiency is defined as the ratio of the observed output to the corresponding potential output given the production frontier, and given that the special production function, was estimated as follows:

$$Y_{it} = f(X_{it}, \beta) \cdot \exp(v_{it} - u_{it}), \tag{4}$$

Therefore, the technical efficiency can be defined as follows:

$$TE_{it} = \frac{f(X_{it}, \beta) \cdot \exp(v_{it} - u_{it})}{f(X_{it}, \beta) \cdot \exp(v_{it})} = \exp(-u_{it}) \tag{5}$$

3.1.3. Tobit regression

The Tobit model has several advantages compared with the ordinary least squares regression when including both continuous variables and discrete variables (Olagunju and Ajiboye, 2010; Peterson, 2005). The technical efficiency of livestock production varies from 0 to 1. Therefore, we used the Tobit model to analyze the effects of extreme drought and the adaption measures to extreme drought on the technical efficiency of livestock production as follows:

$$y_i = \beta_0 + \sum_{j=1}^{k} \beta_j z_{ij} + \varepsilon_i \tag{6}$$

$$y_i = \begin{cases} 0, & if \quad y_i^* \in (-\infty, 0] \\ 0, & if \quad y_i^* \in (0, 1] \\ 0, & if \quad y_i^* \in (1, +\infty] \end{cases} \tag{7}$$

where y_i represents the technical efficiency of livestock production in household i, and z_{ij} includes the various influencing factors on the technical efficiency of livestock production.

3.2. Data

To calculate the frequency of extreme drought, the data including daily precipitation, daily average temperature, daily maximum temperature, daily minimum temperature, sunshine hours, daily average relative humidity, and daily average precipitation of 12 meteorological stations in the Hulun Buir area from 1981 to 2015 were provided by Data Center Resources and Environment, Chinese Academy of Science. In order to explore climate adaptation of vulnerable households in the face of extreme drought, the Center for Chinese Agricultural Policy, Chinese Academy of Sciences, conducted two rounds of field work in Hulun Buir in 2016. Household data were derived from the questionnaire survey with stratified random sampling, covering 6 counties, 14 towns, and 32 villages in Hulun Buir. The questionnaire surveys were carried out in 138 pasturing/farming households, with 126 valid questionnaires (92%). The questionnaire included data on

population, labor, land area, capital, livestock production, income, sale of animal products, and related climate change adaptation measures.

To evaluate the technical efficiency of livestock production of 126 households, we provided the summary statistics of the outputs and inputs for estimating the stochastic frontier production function from the input−output viewpoint (Table 1). We used grassland area (x_1), labor (x_2), and capital (x_3) as the input and the output of total meat (y) as the output. Specifically, grassland area (x_1) was the sum of pasture areas a household owned. Labor (x_2) was the family labor for grazing, sheepshearing, and milking. Capital (x_3) included resources for livestock production, such as breeding stock, transportation vehicles, and livestock housing. The output of total meat (y) included the total output of the meat of pigs, cattle, and sheep, including the meat at the end of the year and the meat sold during the year, and excluding the initial meat at the start of the year. The influencing factors of the household-level technical efficiency of livestock production were: household size (z_1), livestock density (z_2), the frequency of extreme drought (z_3), and the dummy variables of adaptation measures in response to extreme drought including whether the household purchased more forage (z_4), whether the household sold more livestock (z_5), and whether the household reared livestock in fenced enclosures (z_6). Household size (z_1) indicated the population of each household. Livestock density (z_2) indicated the average stocking of sheep (equivalent unit, 1 pig = 5 sheep, 1 cattle = 5 sheep) on the grassland area, measured as the number of animals per mu. The influencing factors were selected based on the general-to-specific modeling method (Campos et al., 2005), which meant we initially estimated the model including other farm-specific variables such as the subsidy from government, nonproductive capital, education status of the household, and other adaptation measures such as disaster insurance. Then, the variables were tested based on the likelihood ratio test. The least significant variables were dropped, and the model was estimated again until all the significant variables passed the likelihood ratio test at the 10% level. Descriptive statistics for the variables used in the Tobit regression are also shown in Table 1.

4. Results and discussion

4.1. Evaluation of extreme drought

4.1.1. Interannual changes of extreme drought

The statistical method for determining interannual changes of extreme drought is to calculate the standardized variables of the surface humidity index from month to month, and then calculate the monthly variation of the surface humidity index of each month (≤ -0.5) as the occurrence frequency of extreme drought in that year. Fig. 3 shows the interannual changes of extreme drought in Hulun Buir during 1980−2015. The average occurrence frequency

of extreme drought in Hulun Buir during this period was 4.6 month/year. The rate of extreme drought change showed a slight downward trend as a whole and the reducing rate was 0.024 month/year. There were also obvious differences in different periods. The overall rate of change increased since 2000. There were two periods of obvious extreme drought in Hulun Buir after 2010 (i.e. 6.27 months/year in 2010 and 6.09 months/year in 2015).

4.1.2. Spatial variation of extreme drought

The frequency of extreme drought in Hulun Buir displayed significant spatial differences during 1980−2015, with a decreasing trend from southwest to northeast (Fig. 4). Extreme drought occurred most frequently in Xin Barag Right Banner, at between 6.52 and 7.75 months/year, and Xin Barag Left Banner and Zhalan Tun followed Xin Barag Right Banner closely, at between 4.64 and 6.52 months/year. The lower frequency of extreme drought took place in Prairie Chenbarhu Banner, Ewenki Autonomous Banner, Arun Banner, and the south of Yakeshi, ranging from 3.20 to 4.64 months/year. The most peaceful places, the north of Yakeshi, Genhe, and Oroqen Autonomous Banner, had the lowest frequency of extreme drought, varying from 1.69 to 3.20 months/year. The spatial match between frequency of extreme drought and precipitation indicated a strong relationship between the frequency of extreme drought and precipitation (Figs. 1 and 4), namely the extreme drought mostly occurred in the regions with less precipitation.

4.1.3. Spatial variation of the inclination rate of extreme drought

There was considerable spatial difference in the inclination rate of extreme drought, indicating the frequency of extreme drought decreased in the southwest but increased in the northeast during 1980−2015 (Fig. 5). But as a whole, in most of the regions in Hulun Buir, the frequency of extreme drought decreased during 1980−2015. The study area could be divided into three parts according to the extent of reducing in extreme drought as follows: (1) Significant decreasing regions. The frequency of extreme drought decreased most significantly in these regions, mainly including Xin Barag Right Banner, Xin Barag Left Banner, Zhalan Tun, the south of Arun Banner, and the south of Ergun, and the inclination rate of extreme drought varied from −0.058 to −0.028 months/year (2) Moderate decreasing regions. The frequency of extreme drought decreased moderately in these regions, mainly including Prairie Chenbarhu Banner, Ewenki Autonomous Banner, the south of Yakeshi, the north of Arun Banner, the north of Ergun, Oroqen

Table 1
Summary statistics of variables used in technical efficiency estimation and Tobit regression.

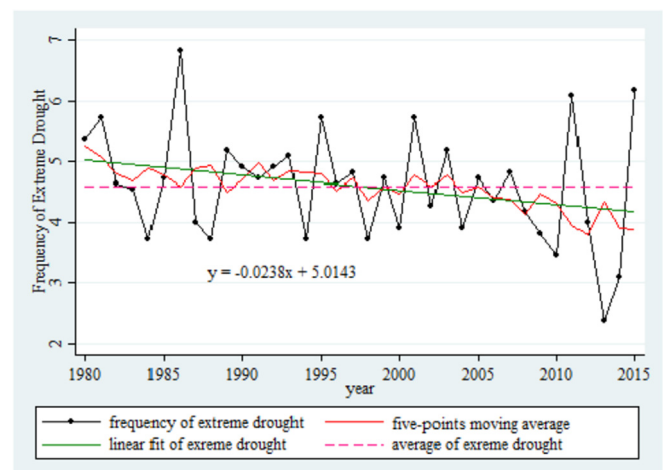| Variable	Unit	Obs	Mean	Std. Dev.
x1	ha	126	201.40	202.49
x2	herd	126	3.03	1.58
x3	Yuan	126	80641.43	123806.20
y1	kg	126	18529.52	16821.17
z1	herd	126	3.32	0.99
z2	sheep unit/ha	126	6.75	11.1
z3	month/year	126	4.73	1.36
z4	–	126	0.70	0.46
z5	–	126	0.63	0.48
z6	–	126	0.14	0.35

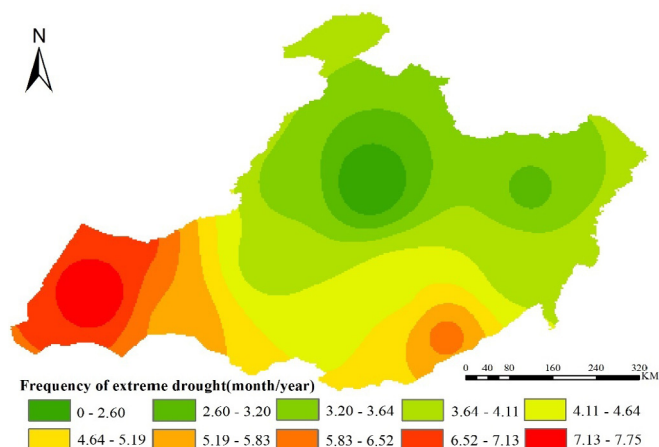**Fig. 3.** Interannual changes of extreme drought in Hulun Buir during 1980−2015.

Fig. 4. Spatial distribution of the average extreme drought in Hulun Buir during 1980–2015.
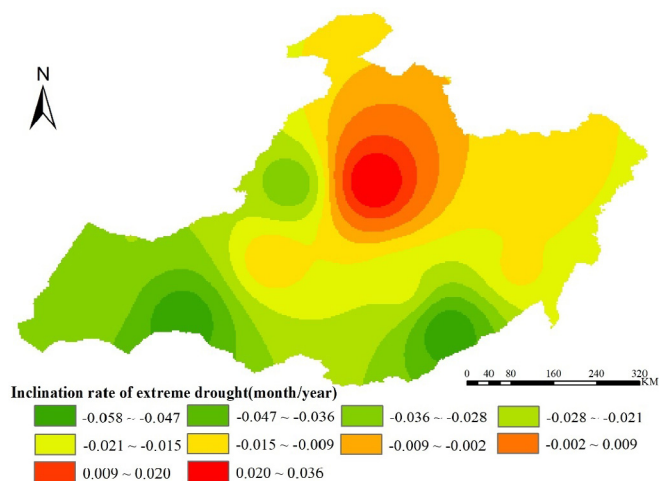

Fig. 5. Spatial distribution of the inclination rate of extreme drought in Hulun Buir during 1980–2015.

Autonomous Banner, and the inclination rate of extreme drought ranged from −0.028 to 0 months/year (3) Increasing regions. The frequency of extreme drought continued to increase in these regions, mainly including the north of Yakeshi and Genhe, and inclination rate of extreme drought changed from 0.00 to 0.036 months/year.

4.2. Evaluation of technical efficiency of livestock production

4.2.1. Parameter estimation

We estimated the translog form of the stochastic frontier production function. Table 2 reveals that all the estimated parameters of the term in a linear equation of the inputs were statistically significant within the 5% level. The coefficients of grassland area, labor, and capital were positive, implying that the larger the grassland area, labor, and capital, the higher the output of meat. In particular, each 1% increase of grassland, labor, and capital resulted in 0.43%, 0.36%, and 0.16% increase in the output of the total meat, respectively.

4.2.2. Analysis of technical efficiency of livestock production

We estimated the technical efficiency of livestock production

Table 2
Parameter estimates based on SFA.

ly1	Coef.	Std. Err.	z	[95% Conf.	Interval]
lx2	0.361**	0.179	2.020	0.011	0.711
lx3	0.163**	0.067	2.410	0.031	0.295
lx1	0.434***	0.098	4.450	0.243	0.626
lx1x2	0.051	0.112	0.450	−0.170	0.271
lx1x3	−0.090**	0.042	−2.130	−0.174	−0.007
lx2x3	0.035	0.115	0.300	−0.191	0.260
lx2sq	0.470	0.505	0.930	−0.520	1.460
lx3sq	−0.052	0.067	−0.770	−0.184	0.080
lx1sq	0.073	0.073	1.000	−0.071	0.217
cons	0.771***	0.160	4.820	0.457	1.084
Number of obs = 126 Log likelihood = −129.674					

Note: * significant at 10%; ** significant at 5%; *** significant at 1%.

and found that the average technical efficiency of livestock production of 126 households was 0.530 in 2015, indicating that the technical efficiency was still in an inefficient state and could be greatly improved. Fig. 6 shows that the distribution of the technical efficiency of livestock production of 126 households in Hulun Buir was skewed to the left, which satisfies the hypothesis of the estimation model. It was also found that almost half of the 126 households were in the range from 0.530 to 0.746. The technical efficiency of livestock production was >0.746 in 13% of households and <0.530 in 41% of households.

4.3. Effects of adaptations to extreme drought on the technical efficiency of livestock production

4.3.1. Climate adaptation of vulnerable households to extreme events

Based on the field survey data in Hulun Buir area in 2016, we summarized the pasturing households' perception to extreme events and especially the adaptation measures to extreme drought (Fig. 7). We found that most of the extreme events that the local households mentioned during the interview were extreme drought, accounting for 68% of the total frequency. Among the adaptation measures the local households adopted, purchasing more forage, selling livestock, and rearing livestock in fenced enclosures in winter were most frequently used, accounting for 39%, 33%, and 12% of the total frequency, respectively. These adaptation measures have changed drastically from the traditional adaptation measures such as mobility, storage, and communal pooling (Agrawal, 2010). In fact, with the reform of the property right system, the implementation of grassland management policy in China, the original collective management of pasture and livestock has transformed into individual management in livestock production, leading to the decrease in the adaptation measures such as mobility and communal pooling (Gongbuzeren et al., 2015). Instead, the vulnerable households increasingly adapt to the effects of extreme drought by market-based approaches such as purchasing more forage and selling livestock. Xie and Li, 2008 also highlighted new adaptation measures focusing on seeking new market-based approaches instead of traditional adaptation strategies such as mobility.

4.3.2. Effects of adaptations to extreme drought on technical efficiency of livestock production

Tobit regression results (Table 3) revealed that livestock density had a positive effect on technical efficiency of livestock production at the household level, indicating that when the livestock density increased, the technical efficiency of livestock production increased. This was mainly because of the intensive feeding and management of livestock. But in the practical production process,
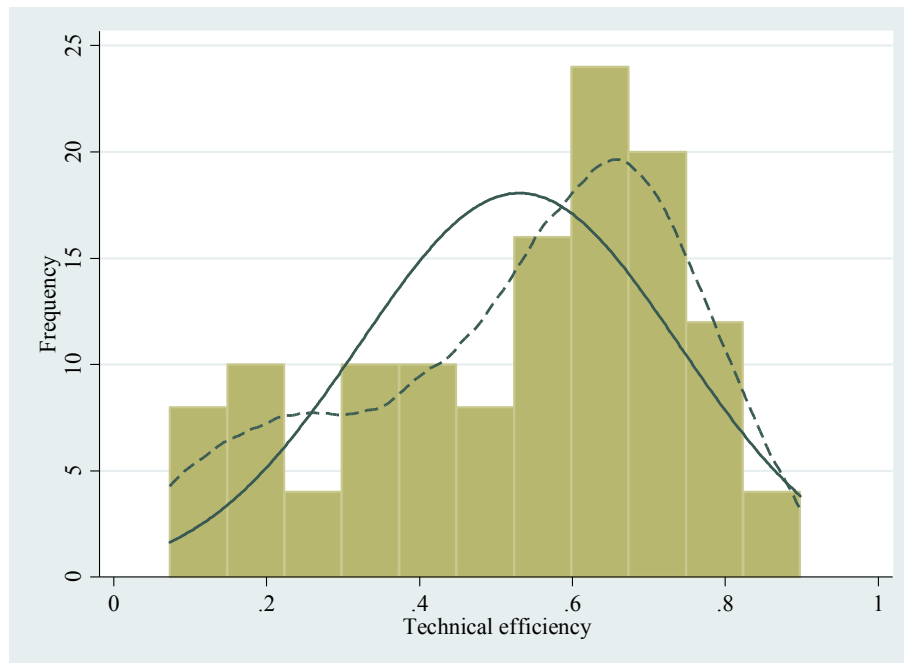
Fig. 6. Distribution of the technical efficiency of livestock production of 126 households.
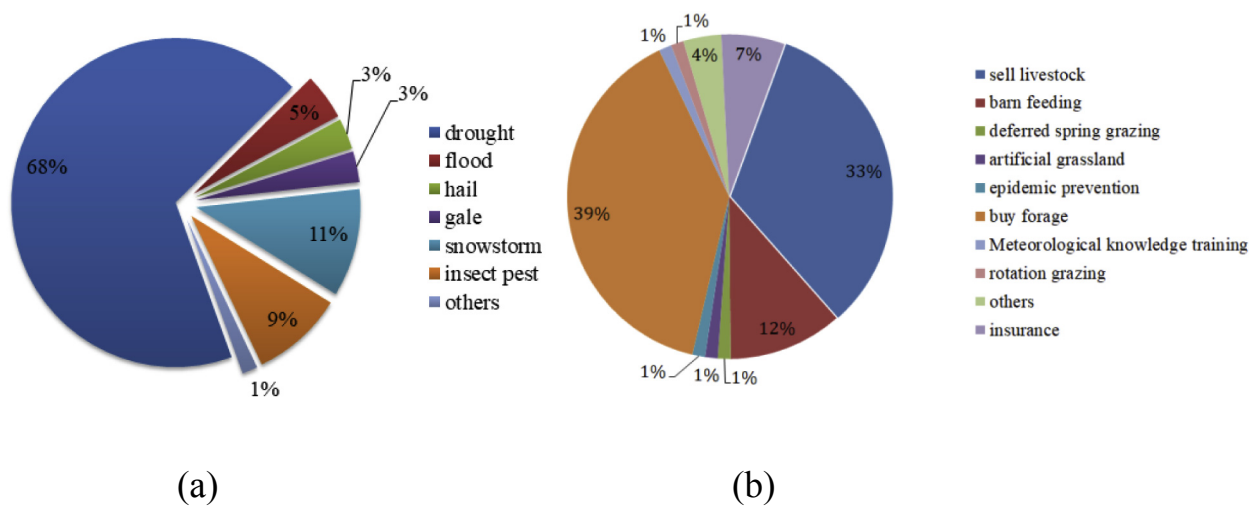

(a)

(b)

Fig. 7. Households' perception (a) and adaptation measures (b) to extreme drought.

Table 3
Technical efficiency of livestock production influencing factors with Tobit regression.

te	Coef.	Std. Err.	t	[95% Conf.	Interval]
z1	−0.039	0.031	−1.270	−0.100	0.022
z2	0.013**	0.006	2.300	0.002	0.025
z3	0.020	0.034	0.580	−0.048	0.087
z4	0.210***	0.029	7.190	0.152	0.268
z5	0.180***	0.026	6.900	0.128	0.231
z6	0.109***	0.029	3.770	0.052	0.167
cons	0.260	0.045	5.770	0.171	0.349

Note: * significant at 10%; ** significant at 5%; *** significant at 1%.

we also should consider the ecological carrying capacity of the grassland area. For this reason, the Chinese government implemented the "sustainable forage supply-livestock balances" policy in 2009. The adaptations of the households had a significant positive effect on technical efficiency of livestock production, whereas the extreme drought index had a significant positive effect on technical efficiency of livestock production when the adaptation measures were introduced in the econometric model. This indicates that pasturing households established effective adaptation measures in the face of the extreme drought in Hulun Buir. In addition, the adoption of purchasing more forage and selling more livestock were the two most effective adaptive measures for the vulnerable households in Hulun Buir in response to extreme drought risks.

5. Conclusion

Extreme climate events have become more frequent and more severe as a result of climate change. In this paper, we first

recognized the most frequent extreme climate events, extreme drought, in a semi-arid region, Hulun Buir, Inner Mongolia, China. We further investigated climate adaptations of the local vulnerable households to extreme drought and its impact on livestock production. We applied the FAO Penman–Monteith model to calculate the frequency of extreme drought, analyzed the spatio-temporal variation characteristic of extreme drought during 1980–2015, and applied SFA to measure the technical efficiency of livestock production of 126 households based on the results of field research. Furthermore, we explored the effects of climate adaptation to extreme drought on technical efficiency of livestock production by econometric analysis.

The results showed that the average occurrence frequency of extreme drought in Hulun Buir from 1980 to 2015 was 4.6 month/year. Although the rate of extreme drought change showed a slight downward trend, there were two peaks in frequency of extreme drought within the latter 5 years (2010 and 2015). The frequency of extreme drought displayed a significant spatial difference during 1980–2015, with a decreasing trend from southwest to northeast. We used this result of frequency of extreme drought as an added indicator to further analyze the effects on livestock production.

Based on the survey data, the average technical efficiency of livestock production of the local households was 0.530 in 2015, indicating that the technical efficiency was still in an inefficient state and could be greatly improved. The adaptation of the households had a significant positive effect on the technical efficiency of livestock production, whereas the extreme drought index had no significant effect on technical efficiency of livestock production when the adaptation measures were introduced in the model. Market-based adaptation measures such as purchasing more forage and selling more livestock were the two most frequently adopted and most effective adaptive measures for vulnerable households in Hulun Buir in response to extreme drought risks in recent years, because of the reform of property right system the implement of grassland management policy in China.

Although the current market-based adaptation measures are beneficial for livestock production, we should also consider the negative effects of current adaptation measures on the pastoral ecological environment. During drought years, purchasing forage may lead to overgrazing. Therefore, the government needs to implement management of grazing capacity by controlling forage input, as well as providing a subsidy to make up for a loss of animal husbandry and encourage herder households to control grazing capacity. Moreover, under the current condition of the reform of property right system and the implement of grassland management policy in China, the government should consider providing more opportunities for the selection of adaptation measures by households and helping them to restore the traditional low-cost adaptation strategies. This could help the vulnerable households avoid the risks caused by the uncertainty of the current social and economic environment. The government could restore common property management or establish rural co-operatives, which would help to restore the movement of livestock, providing a wider range of forage to households and balancing the grazing intensity of different pastures.

Conflicts of interest

The authors declare no conflict of interests.

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